Applying CERES Calibration Techniques to the CLARREO Mission

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Clouds and Earth's Radiant Energy System (CERES) Radiometry – State of the Art for Broadband UV to far IR Measurements

The CERES sensor design is shown in Figure 1. Including the CERES predecessor Earth Radiation Budget Experiment (ERBE) sensors these series of instruments have been measuring solar reflected radiation, thermal emitted radiation, and total radiation from the Earth globally for more than 25 years. The 4 CERES sensors currently operating in orbit have been measuring the reflected and emitted radiation in 3 spectral bands at accuracies shown in Figure 2 for significantly longer than their 5 year design life. Three broadband radiometers scan across the Earth's surface and beyond the limb on each side in 6.6 sec with 30 Km spatial resolution samples. On each scan the radiometers are calibrated against deep space to obtain a zero radiance and also view an internal calibration source with highly stable, repeatable blackbody and lamp sources.

Channel	Wavelength Range	Radiometric Accuracy End of Life (5 yrs)
Shortwave	0.3 to 5.0 µm	<1.0%
Longwave or Window	8.0 to 12.0 µm	<0.3%
Total	0.3 to >50 µm	<0.5%

Figure 2. Spectral bands and radiometric accuracies of the CERES sensor channels.

CERES Radiometric Calibration Process[1]

The key features of the CERES Radiometric Calibration approach are as follows:

- Characterization of the spectral performance, offsets, stability/repeatability, dynamic range, linearity, point target response, and noise performance for each channel
- Ground calibration in thermal vacuum environment traceable to ITS-90 via temperature scale AND electrical power scale using tailored blackbody sources and a cryogenic active cavity radiometer
- Use of multiple cross-calibration paths between multiple sources, detectors, and across CERES channels
- Transfer of calibration from ground sources to in-flight sources during the ground calibration process
- Highly stable, repeatable (~0.1%) in-flight calibration sources with multiple cross-check paths, i.e. detectors to monitor the lamp source, cross-calibration with solar source via mirror attenuator mosaic (MAM), two blackbodies (see Figure 3)
- On-orbit trending, cross-calibration between CERES sensors

Ground Calibration

CERES ground calibration is performed in NGST's Radiometric Calibration Facility[2] shown in Figure 3. Each CERES instrument is installed on a carousel assembly in the center of the 8 ft. diameter x 12 ft. long thermal vacuum chamber. This allows the sensor channels to view the various calibration sources inside the chamber. On the opposing side of the carousel a cryogenic Transfer Active Cavity Radiometer (TACR) is used to (a) provide calibration traceability via the electrical power substitution path and (b) transfer radiometric calibration from the extremely accurate Narrow Field Blackbody (NFBB) with radiance traceable through the temperature scale to the highly stable and uniform Shortwave Reference Source (SWRS) on the opposing end of the chamber. Features of the facility include:

- The NFBB is designed with no views to seams or scattering sources and is painted with a specular black paint, enabling multi-reflections to assure high emittance, measured at 0.999994
- NFBB is highly conductive with thermal gradients <7mK and temperature is measured via 7 platinum resistance thermometers (PRT's) with calibration traceable to ITS-90 at <23 mK. The blackbody temperature is controlled to <5 mK.
- Liquid Nitrogen cooled blackbodies with cold baffles enable zero calibration at the beginning of each CERES crosstrack scan.
- The Wide Field Blackbody (WFBB) was the standard for the ERBE missions and supports traceability back to those instruments. It also supports calibration stability measurements vs wide scan angles.
- A Zero Radiance Reference (ZRR) cryogenic blackbody in a long arc shape allows CERES to cover the complete scan range to check for zero offsets/drifts with scan angle
- The SWRS consists of highly stabilized (<0.14%/hours) lamp source, set of characterized bandpass filters, and a highly uniform (<0.5%) Spectralon integrating sphere. The output of this source is calibrated via the TACR.

CERES In-Flight Calibration Sources

The in-flight calibration sources, shown above in Figure 4, include the following features:

- Two identical concentric-ring blackbody sources with precision temperature control at <0.1K and redundant temperature sensors calibrated to <0.03K
  - Longwave channel views one blackbody, Total channel views other
  - Blackbodies can be commanded from 253K to 303K
- Shortwave Source includes incandescent lamp with highly stable, repeatable current driver, diffuser, and photodetector for cross-calibration
  - Photodetector used as cross-check against lamp stability
  - Source viewed by CERES Shortwave channel
- Mirror Attenuator Mosaic (MAM) supplies diffuse solar illumination to Shortwave and Total channel sensors
  - Baffle (not shown) limits viewing to particular solar angles
  - All reflective design minimizes susceptibility to UV degradation found in white paints and Spectralon

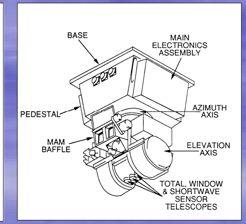

Figure 1. CERES Scanning Radiometer

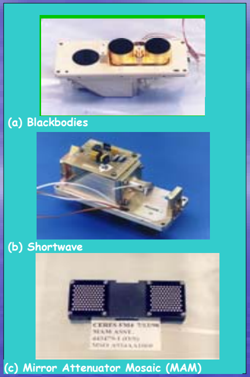

Figure 4. CERES In-Flight Calibration Sources

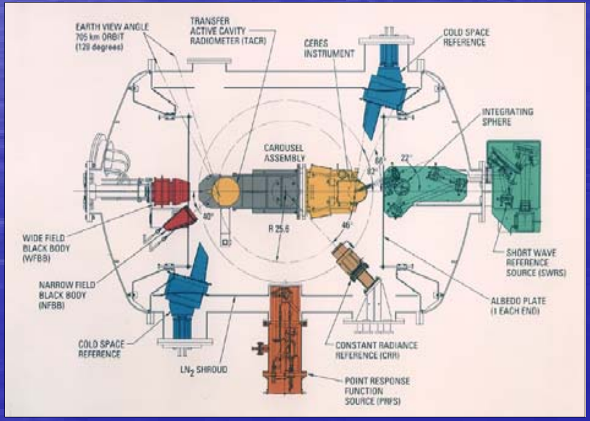

Figure 3. NGST Radiometric Calibration Facility Layout

Summary

CERES is one of the most accurately calibrated radiometer in orbit today. By exploiting the techniques, processes, and facilities used to calibrate CERES for the CLARREO Mission, accommodating the differences between the sensors (e.g. spectrally resolved vs broadband radiometry, potentially FTS spectral scanning vs fixed spectral bandpass), and incorporating new advanced in-flight calibration capabilities (e.g. melting-point temperature control/measurement) the CLARREO mission should achieve its goal of providing state-of-the-art absolute calibration to Earth radiation budget measurements as well as cross-calibration of Earth-viewing space assets.

Acknowledgements

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References:

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CLARREO Mission Description

CLARREO will be the most accurately calibrated sensor in orbit when it flies (see Figure 5)[4]. This calibration must continue "in perpetuity" to (a) provide the basis, via cross-calibration, for calibrating all other spaceborne sensors and (b) accurately monitor changes in the Earth climate over decades. This will require:

- A shortwave imaging spectrometer covering the 0.38 to 2.5 µm wavelength range
- A longwave spectroradiometer covering the 5 to >100 µm, likely two Fourier Transform Spectrometers, one from 5 to 15 µm, one from 15 to >100 µm
- Orbital configurations that can monitor diurnal variations as well as enable coincident viewing of an Earth location with other instruments for cross-calibration
- New, state-of-the-art in-flight calibration sources to improve calibration accuracies
- Shortwave and Longwave instrument designs that are highly conducive to calibration while also supporting the spectral range, spectral resolution, data rates, and other necessary instrument performance parameters
- Ground calibration sources that provide calibration references over decades

Channel	Wavelength Range	Spectral Resolution	Spatial Resolution	Radiometric Accuracy End of Life (10 yrs)
Shortwave	0.38 to 2.5 µm	5 to 15 nm (TBR)	1 Km with 100 Km swath	<0.25%
Longwave	5.0 to >100 µm	0.1 cm^{-1} (goal)	50 to 100 Km	<0.1K (~0.1%)

Figure 5. CLARREO Initial Calibration Requirements

CLARREO Radiometric Calibration Needs

- Broad wavelength range 0.38 to 100 µm
- Improved absolute accuracy over CERES at <0.3% over 10 years (goal)
- Spectral calibration at <0.1 cm^{-1} (goal) accuracy over 10 years
- Detectors will be photon detectors vs bolometers, improving noise performance but increasing the challenges of detector temporal and spectral variability
  - May require absolute standards on-orbit vs stable in-flight sources with ground calibration standards
  - Calibration updates in operation will be required on timeframe of seconds
- Use of Fourier Transform Spectrometers implies additional calibration challenges given calibration is in transform space, compounding spectral and radiometric error terms
- Thermal control for a larger optical system with photon detector sensitivities will be more challenging
- Polarization must be characterized at the 0.1% accuracy level

CLARREO In-Flight Calibration Blackbody Design

- Melting point temperature control/measurement underway at Univ of Wisconsin[3] valuable for improving temperature accuracy
- NFBB-like blackbody with specular black surfaces, high temperature uniformity, no visible seams or cone tips, and characterized at 0.05% level is required to guarantee high emittance & temperature uniformity
- Stray light outside instrument aperture/field of view must be measured and corrected during the calibration process
- System design to enable on-orbit end-end calibration including all optics is required
- Design must include secondary calibration paths to eliminate systematic error terms, e.g. CERES shortwave lamp source also carries photodetector and is cross-calibrated against the Sun via the MAM

CLARREO Ground Calibration Concept

- Relative spectral calibration required to >100 µm
  - CERES uses a FTS as source and spectrally scans over broadband range of the CERES radiometer channels
  - Assuming CLARREO is FTS-based IR instrument it will require stable, known, narrow band source at variable wavelengths across spectral range. A grating monochromator source in cold thermal vacuum environment would enable spectral characterization of the CLARREO response.
- Absolute calibration could be accomplished using facility similar to NGST's RCF
  - CLARREO should reproduce the broadband blackbody curve @ <0.1% level when viewing NFBB
  - NFBB temperature range covers scene dynamic range
  - Zero radiances available by viewing the cold space references and constant radiance reference sources
  - Shortwave calibration requires replacing the SWRS source with tunable, monochromatic source similar to NGST's Hyperspectral Test Bed used to calibrate the EO-1 Hyperion hyperspectral imager
    - Lamp source with monochromator sets spectral bandwidth
    - Integrated output of narrow band source measured with TACR at each wavelength
    - Integrating sphere from current RCF maintained in system for spatial uniformity
- All calibration to be completed in thermal vacuum environment that accurately simulates the on-orbit environment for both shortwave and longwave instruments